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Abstract: Treatment of 4,4-disubstituted 2-phenyl-1,3-thiazole-5(4H)-thiones with lithium diisopropylamide (LDA; LiNiPr2) in THF at -78° yielded the corresponding 1,3-thiazole-5(4H)-thioles in moderate yields. Sequential treatment with LDA and MeI under the same conditions led to the 5-methylsulfanyl derivatives. Similarly, reaction of some cycloalkanethiones as well as diaryl thioketones with LDA and MeI gave cycloalkyl methyl sulfides and diarylmethyl methyl sulfides, respectively. A reaction mechanism via H transfer from LDA to the thiocarbonyl C-atom via a six-membered transition state is proposed for this unprecedented reduction of the C¼S bond.

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Reduction of Thiocarbonyl Compounds with LDA

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Dedicated to Professor *Hans-Ulrich Reissig*, Freie Univeristät Berlin, on the occasion of his 65th birthday

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Treatment of 4,4-disubstituted 2-phenyl-1,3-thiazole-5(4*H*)-thiones with LDA in THF at –78° yields the corresponding 1,3-thiazole-5(4*H*)-thioles in moderate yield. Sequential treatment with LDA and MeI under the same conditions leads to the 5-methylsulfanyl derivatives. Similarly, reaction of some cycloaliphatic as well as diaryl thioketones with LDA and MeI gives cycloalkyl methyl sulfides and diarylmethyl methyl sulfides, respectively. A reaction mechanism *via* hydride transfer from LDA onto the thiocarbonyl C-atom *via* a six-membered transition state is proposed for this unprecedented reduction of the C=S bond.

1. Introduction. – For the synthesis of five-membered S-heterocycles, 1,3-dipolar cycloadditions with C=S compounds [1] or S-containing 1,3-dipoles [2] are of continuing interest. In the past, we have reported on various types of [2+3]-cycloadditions with 1,3-thiazole-5(4*H*)-thiones of type **1** as a model for C=S dipolarophiles [3]. For example, reactions with thiocarbonyl ylides led to spirocyclic 1,3-dithiolanes [4], diazoalkanes reacted with **1** to give spirocyclic 2,5-dihydro-1,3,4-thiadiazoles [5], and reactions with azomethine ylides yielded spirocyclic 1,3-thiazolidines [6]. Differently substituted azomethine ylides have been generated *in situ* in the presence of **1** by using various methods (*cf*. [7]), such as thermal ring opening of aziridines [6c,d] or desilylation of *N*-[(trimethylsilyl)methyl]amino ethers [6e].

Within these studies, we have also tried to generate the C-unsubstituted *N*-methylazomethine ylide following the protocol of *Roussi* and coworkers [8]. These authors reported that the treatment of trialkylamine *N*-oxides in THF with LDA at 0° in the presence of C=S dipolarophiles leads to the corresponding [2+3]-cycloadducts (1,3-thiazolidine derivatives). For example, the reaction of trimethylamine oxide (**2**) with LDA in the presence of thiobenzophenone or adamantanethione, respectively, gave the corresponding *N*-methyl-1,3-thiazolidines **3** (*Scheme 1*). As a rationalization of the formation of five-membered N-heterocycles, the dehydration of the N-oxides to give an azomethine ylide as a reactive intermediate was proposed. Unexpectedly, the analogous treatment of a mixture of the 1,3-thiazole-5(4*H*)-thione **1a** and **2** with LDA at 0° carried out in our laboratories gave only the reduction product **4a**, and none of the expected cycloadduct could be detected.

Scheme 1

The use of LDA as a strong base in organic synthesis, *e.g.,* for the deprotonation of CH-acidic compounds, is well known [9]. Less-well known is the function of LDA as a reducing agent [10], *e.g.*, in the reduction of nitroarenes to the corresponding anilines and azoxyarenes *via* a single elctron transfer (SET) mechanism [10a]. Furthermore, treatment of 4-fluorotoluene **5** with lithium diethylamide in Et_2O led to a mixture of the *meta*- and *para*-isomers of ethyl(α-tolylethyl)amine (**6**) and *N,N-dimethyltoluidine* (**7**) as well as toluene [11] (*Scheme 2*). The formation of **6** was explained by a hydride transfer from $LiNEt_2$ to the intermediate aryne followed by nucleophilic addition of the aryl anion at the formed imine. But to the best of our knowledge, there is no hydride transfer reaction of LDA known.

Scheme 2

The aim of the present study was to evaluate the ability of LDA as a hydride transfer reagent in thiocarbonyl chemistry.

2. Results and Discussion. – As mentioned above, treatment of a mixture of equimolar amounts of 4,4-dimethyl-2-phenyl-5(4*H*)-thione (**1a**) and trimethylamine *N*-oxide (**2**) in THF at 0° with 3.5 equivalents of LDA led to the corresponding 4,5-dihydro-1,3-thiazole-4-thiole **4a** [12], which was isolated in 40% yield, as the major product. This surprising result motivated us to investigate reactions of C=S containing compounds with LDA. First, the reaction with **1a** was repeated in the absence of the *N*-oxide **2** at –78° by using 1.6 equivalents of LDA. Under these conditions, only one product, **4a**, was formed, which after treatment with an aqueous 20% NH_4Cl solution was isolated in 69% yield. An

analogous result was obtained with the spirocyclic **1b**, 2-phenyl-3-thia-1-azaspiro[4.4]non-1-ene-4-thione (63% yield of **4b**; *Scheme 3*). This outcome suggests a carbophilic addition of a hydride ion onto **1**, leading to an intermediate thiolate **8**. Therefore, **1a** and **1b**, respectively, in THF at –78° were treated with 1.6 equivalents of LDA. After stirring for 15 min, one equivalent of MeI was added, the mixture was allowed to warm to room temperature, and then poured on ice. Usual workup gave the corresponding 5-methylsulfanly derivatives **9a** [13] and **9b** in 68 and 80% yield, respectively. Unfortunately, the analogous reactions with 2-benzyl- and 2-phenylthio-1,3-thiazol-5[4*H*)-thion **1c** and **1d** failed.

Scheme 3

With the aim of excluding the possibility that the H-atom at C(5) of the reduction products **4** and **9** stems from the solvent, the reaction with **1a** was repeated in (D_8)THF with freshly prepared LDA as well as with the commercially available 2M LDA-solution in THF. In both cases, the formed **4a** did not contain any D-atom. Therefore, we concluded that LDA acted as a hydride donor in this reaction.

Motivated by these results, we were interested to extend the scope of this reduction process to thioketones. Because of the easier workup and purification, the probably formed thiolate should be trapped *via* methylation. First, two cycloaliphatic thioketones, adamantanethione (**10a**) [14] and pentacyclo[5.4.0^{2,6}.0^{3,10}.0^{5,9}]undecane-8-thione (**10b**) [15], in THF/heptane/ethylbenzene at –78° were treated with ca. 1.25 equivalents of LDA for 10 min. Then, excess MeI was added at the same temperature, the mixture stirred for another 10 min, and the reaction quenched by addition of H_2O. The yields of the methyl

thioethers **11** were estimated on the basis of ^{1}H-NMR spectra of the crude mixture to be in the range of 70–80%. After chromatographic purification, the cycloalkyl methyl sulfides **11a** [16] and **11b** were obtained in 42 and 47%, respectively (*Scheme 4*). We propose that the methylsulfanyl group of **11b** is *endo* oriented as the result of an *exo*-addition, in analogy to other nucleophilic additions with pentacyclo[5.4.0^{2,6}.0^{3,10}.0^{5,9}]undecan-8-one [15a][17].

Scheme 4

Surprisingly, 1,1,3,3-tetramethylindane-2-thione did not react under the same conditions, and performing the reaction at –40° with three equivalents of LDA provided a complex mixture containing traces of the expected sulfide and numerous byproducts. Similarly, neither di(*tert*-butyl)thioketone nor 2,2,4,4-tetramethyl-3-thioxocyclobutanone did undergo a reaction with LDA. Most likely, steric hindrance is the reason for the failure.

Next, the reaction with aromatic thioketones was examined. Treatment of thiobenzophenone (**10c**) [18] as well as thiodibenzosuberone (**10d**) [19] with ca. 1.25 equivalents of LDA and subsequent treatment of the initial product with MeI led to the corresponding methylsulfides **11c** [20] and **11d**, respectively, which were isolated in 52 and 41% yield (*Scheme 4*). On the other hand, the analogous reaction of the hetarylthioketones phenyl(2-thienyl)methanethione (**10e**) [21] and di(selenophen-2-yl)methanethione [22] led to complex mixtures of diverse products, and only in the case of **10e**, the corresponding methylsulfide **11e** was obtained in very low yield (9%). Finally, the reduction of diferrocenylthioketone (**10f**) was performed successfully by using 3.2 equivalents of LDA

and 6.5 equivalents of MeI. After chromatographic workup, the hitherto unknown diferrocenylmethyl methyl sulfide **11f** was obtained in 37% yield.

Thiofluorenone (**10g**) [18][23] is a prominent representative of aromatic thioketones, known as a superdipolarophilic agent [2]. But the attempted reduction of **10g** with LDA failed, and only traces of the desired methylsulfide were detected in the crude mixture by ^{1}H-NMR spectroscopy. The major product was the known bisfluorenylidene (= 9-(9*H*-fluoren-9-ylidene)-9*H*-fluorene, **12**) [24] (*Scheme 5*), accompanied by numerous byproducts.

Scheme 5

As a reaction mechanism for the reduction of thiocarbonyl compounds with LDA, we propose a hydride transfer *via* a six-membered transition state **A**, leading to the thiolate **B** and the imine **C** as a side-product (*Scheme 6*). This transition state resembles that of reactions of sterically demanding *Grignard* reagents with carbonyl compounds bearing bulky substituents, *i.e.* **D** (*Scheme 6*) [25]. Also the $AlMe_3$-catalyzed asymmetric *Meerwein-Schmidt-Ponndorf-Verley* reduction of prochiral ketones with *i*PrOH in the presence of enantiopure BINOL is rationalized by an analogous transition state [26].

Scheme 6

3. Conclusions. - The unexpected hydride transfer of LDA proved to be a useful method for the reduction of 4,4-disubstituted 1,3-thiazole-5(4*H*)-thiones and non-enolizable thioketones leading to the corresponding thiols. This is the first observation of a reaction in

which LDA acts as a hydride donator. Although the scope of the reaction is not fully explored, it is very useful in the series of thioketones. Especially important is the simple access to diaryl/hetaryl methanethiols, which are of great interest from the point of view of materials chemistry.

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Experimental Part

1. *General*. The reactions with thioketones were generally performed under an Ar atmosphere in flame-dried flasks. Solvents and reagents were added by syringe. Tetrahydrofuran (THF) was dried with Na and benzophenone and freshly distilled before use. Other reagents were purchased and used as received without further purification. TLC: *Merck 60 F_{254}* SiO_2-coated Al-plates, 0.2 mm; detection of the substances on the TLC plates under UV light (λ 254 nm) or with $KMnO_4$ soln. Prep. TLC: *Merck 60 F_{254}* SiO_2-coated glass-plates, 2 mm. Column chromatography (CC): *Merck* 60 SiO_2, 0.040 – 0.63 mm. M.p.: *Mettler*-FP-5 or MEL-TEMP II (*Aldrich*) instrument; uncorrected. IR Spectra: *Perkin-Elmer-1600-FT-IR* or *FT-IR NEXUS* spectrophotometer; film or KBr pellets; cm^{-1}.

^{1}H- and ^{13}C-NMR Spectra: *Bruker-AC-300*, *Bruker-ARX-300* instrument (300 and 75.5 MHz, resp.) or *Bruker AVIII 600* instrument (600 and 151 MHz, resp.), in $CDCl_3$; multiplicity of C-atoms from DEPT or 2D spectra (HMQC). MS: *Finnigan MAT-90* or *Finnigan SSQ-700* instrument (EI, 70 eV, or CI (NH_3 or isobutene)) or *Varian 500-MS LC Ion Trap* instrument (ESI-MS). Elemental analyses were performed on *Vario EL* or a *Vario EL III* (*Elementar Analysensysteme GmbH*) instruments.

2. *Starting Materials*. All chemicals were commercially available (*Fluka*, *Aldrich*, and *Merck*). Lithium diisopropylamide (LDA) soln. (2.0 M in THF) or (2.0 M in THF/heptane/ethylbenzene) was purchased from *Fluka* and *Aldrich*, respectively, and used as received. Solvents were purified as follows: hexane: distillation from CaH_2; AcOEt and CH_2Cl_2: distillation from K_2CO_3 and stored over molecular sieves (4 Å); THF (purum, *Fluka*) and Et_2O: dried over Na and distilled; toluene (p.a., *Merck*): stored over Na.

3. *Reactions of 1,3-Thiazole-5(4*H*)-thiones* **1** *with LDA. - General Procedure 1 (GP 1).* To a cooled soln. (–78°) of 4,4-dimethyl-2-phenyl-1,3-thiazole-5(4*H*)-thione (**1a**) or 2-phenyl-3-thia-1-azaspiro[4.4]non-1-en-4-thione (**1b**), respectively (1 mmol) in THF (20 ml) was added a 2M LDA soln. in THF (0.8 ml, 1.6 mmol). The soln. decolorized after a few min, and the mixture was warmed to r.t. Then, a cooled (0°) aq. soln. of NH_4Cl was added and the mixture extracted with Et_2O (3×). The combined org. phase was dried ($MgSO_4$), the solvent evaporated, and the residue purified by prep. TLC (hexane/AcOEt).

General Procedure 2 (GP 2). To a cooled soln. (–78°) of **1a** or **1b**, respectively (1 mmol), in THF (20 ml) was added a 2M LDA soln. in THF (0.8 ml, 1.6 mmol). After stirring for 15 min, MeI (0.06 ml, 1 mmol) was added and stirring was continued at –78° for another 15 min. The mixture was poured into ice-water (100 ml) and extracted with Et_2O (3×). The combined org. phase was dried ($MgSO_4$), the solvent evaporated, and the

residue purified by prep. TLC (hexane/AcOEt).

4,5-Dihydro-4,4-dimethyl-2-phenyl-1,3-thiazole-5-thiole (**4a**) [12]. *GP1*; prep. TLC (hexane/AcOEt 10:1). Yield: 154 mg (69%). Pale yellow oil. IR (film): 2973*s*, 2929*m*, 2561*m* (br), 1596*s*, 1576*s*, 1489*m*, 1447*s*, 1379*m*, 1360*m*, 1313*m*, 1259*s*, 1210*m*, 1174*s*, 949*s*, 847*m*, 823*m*, 765*s*, 690*s*, 614*s*. ^{1}H-NMR (300 MHz): 7.69–7.65 (*m*, 2 arom. H); 7.36–7.28 (*m*, 3 arom. H); 4.65 (*d*, *J* = 9.1, HC(5)); 2.02 (*d*, *J* = 9.1, SH); 1.42, 1.37 (2*s*, 2 Me). ^{13}C-NMR (75 MHz): 163.5 (*s*, C=N); 133.1 (*s*, 1 arom. C); 131.2, 128.4, 128.1 (3*d*, 5 arom. CH); 80.2 (*s*, C(4)); 58.1 (*d,* C(5)); 26.3, 22.6 (2*q*, 2 Me). CI-MS: 226 (10), 225 (14), 224 (100, $[M+1]^{+}$).

4,5-Dihydro-4,4-dimethyl-5-methylthio-2-phenyl-1,3-thiazole-5 (**9a**) [13]. *GP2*; prep. TLC (hexane/AcOEt 5:1). Yield: 161 mg (68%). Pale yellow oil. IR (film): 3061*m*, 3027*m*, 2974*s*, 2918*s*, 2861*m*, 1596*s*, 1577*s*, 1489*s*, 1447*s*, 1380*m*, 1360*s*, 1313*m*, 1296*m*, 1260*s*, 1209*m*, 1175*s*, 1120*m*, 1074*m*, 1028*m*, 1001*m*, 949*s*, 854*m*, 832*s*, 765*s*, 690*s*, 677*s*, 642*m*, 614*s*. ^{1}H-NMR (300 MHz): 7.73–7.69 (*m*, 2 arom. H); 7.36–7.25 (*m*, 3 arom. H); 4.60 (*s*, HC(5)); 2.06 (*s*, MeS); 1.50, 1.36 (2*s*, 2 Me). ^{13}C-NMR (75 MHz): 163.1 (*s*, C=N); 133.2 (*s*, 1 arom. C); 131.1, 128.4, 128.1 (3*d*, 5 arom. CH); 80.6 (*s*, C(4)); 67.5 (*d, C*(5)); 27.1, 23.4 (2*q*, 2 Me); 15.5 (*s*, MeS). EI-MS: 237 (12, M^{+}), 146 (9), 145 (100), 104 (31), 86 (53), 84 (94).

2-Phenyl-3-thia-1-azaspiro[4.4]non-1-en-4-thiole (**4b**). *GP1*; prep. TLC (hexane/AcOEt 10:1). Yield: 156 mg (63%). Pale yellow oil. IR (film): 2976*s*, 2934*m*, 2560*m* (br), 1594*s*, 1570*m*, 1489*m*, 1439*s*, 1360*m*, 1312*m*, 1210*m*, 1172*s*, 954*m*, 839*m*, 819*m*, 755*s*, 683*m*, 629w. ^{1}H-NMR (300 MHz): 7.83–7.78 (*m*, 2 arom. H); 7.47–7.29 (*m*, 3 arom. H); 4.79 (*d*, *J* = 8.4, HC(5)); 2.19–2.10 (*m*, 2 H); 2.22 (*d*, *J* = 8.4, SH); 2.08–1.60 (*m*, 6 H). ^{13}C-NMR (75 MHz): 162.6 (*s*, C=N); 133.1 (*s*, 1 arom. C); 131.1, 128.4, 128.2 (3*d*, 5

arom. CH); 92.1 (*s*, C(4)); 57.6 (*d,* C(5)); 39.7, 36.6, 34.8, 24.5 (4*t*, 4 CH_2). EI-MS: 249 (6, M^+), 216 (30), 171 (100), 156 (9), 143 (8), 121 (22), 104 (59), 77 (31).

4-Methylthio-2-phenyl-3-thia-1-azaspiro[4.4]non-1-en (**9b**). *GP2*; prep. TLC (hexane/AcOEt 5:1). Yield: 212 mg (80%). Colorless oil. IR (film): 3061*m*, 3026*m*, 2959*s*, 2870*s*, 1596*s*, 1577*s*, 1489*s*, 1447*s*, 1313*s*, 1256*s*, 1176*m*, 1157*m*, 1074*m*, 1050*m*, 1021*m*, 993*s*, 942*s,* 832*s*, 766*s*, 690*s*, 611s. ^{1}H-NMR (300 MHz): 7.74–7.71 (*m*, 2 arom. H); 7.34–7.24 (*m*, 3 arom. H); 4.61 (*s*, HC(5)); 2.27–2.22 (*m*, 1 H); 2.20–2.06 (*m*, 1 H); 1.97 (*s*, MeS); 1.95–1.59 (*m*, 6 H). ^{13}C-NMR (75 MHz): 162.7 (*s*, C=N); 133.3 (*s*, 1 arom. C); 130.9, 128.4, 128.1 (3*d*, 5 arom. CH); 91.7 (*s*, C(4)); 66.0 (*d,* C(5)); 39.3, 34.1, 24.9, 23.9 (4*t*, 4 CH_2); 14.0 (*s*, MeS). EI-MS: 263 (10, M^+), 216 (10), 174 (12), 171 (100), 170 (20), 120 (9), 104 (39).

4. *Reactions of Thioketones* **10** *with LDA. - General Procedure 3 (GP 3).* A soln. of thioketone (2.0 mmol) in dry THF (3.0–5.0 ml) was added dropwise to a soln. of LDA (2.0 M in THF/heptane/ethylbenzene, 1.25 ml, 2.5 mmol) at –78° and stirred at this temperature for 10 min. Then, excess MeI (0.45 ml) was added, and the resulting mixture was stirred another 10 min. After addition of H_2O (15 ml), the mixture was extracted with Et_2O (3× 10 ml), the combined org. layers were dried ($MgSO_4$), filtered, and the solvents were removed *in vacuo*. Crude products were purified by flash chromatography (FCC, SiO_2).

2-Adamantyl methyl sulfide (**11a**) [16]. *GP 3*. FCC (petether/CH_2Cl_2 6:1). Yield: 154 mg (42%). Colorless oil. IR (film): 3010–2850, 1450, 1100, 965. ^{1}H-NMR (600 MHz): 2.97 (br. *s*, 1 H); 2.17–2.13 (*m*, 2 H); 2.08 (*s*, MeS); 1.73–2.01 (*m*, 10 H); 1.51–1.56 (*m*, 2 H). ^{13}C-NMR (151 MHz): 55.0 (*d*, CH(2)); 38.7, 37.8 (2*t*); 32.5 (*d*); 31.9 (*t*); 27.8, 27.6 (2*d*); 14.9 (*q*, MeS). ESI-MS: 183 (100, $[M+1]^+$), 135 (63, $[M–MeS]^+$).

Endo-*Pentacyclo[5.4.0.0^{2,6}.0^{3,10}.0^{5,9}]undecan-8-yl methyl sulfide* (**11b**). *GP 3*. FCC (petether/CH_2Cl_2 4:1). Yield: 179 mg (47%). Colorless oil. IR (film): 2970–2830, 1455, 1285. ^{1}H-NMR (600 MHz): 2.73–2.70, 2.59–2.56, 2.55–2.53 (3*m*, 5 H, 2:2:1); 2.43–2.33, 2.26–2.20 (2*m*, 5 H, 2:3); 2.10 (*s*, MeS); 1.70, 1.19 (2*d*, *J* = 10.4, 1 H each); 1.05–1.01 (*m*, 1 H). ^{13}C-NMR (151 MHz): 50.0, 47.0, 46.2, 46.0, 42.4, 42.0, 41.7, 39.3, 36.2 (9*d*); 34.4, 28.2 (2*t*); 17.5 (*q*, MeS). ESI-MS: 193 (100, $[M+1]^+$): Anal. calc. for $C_{12}H_{16}S$ (192.32): C 74.94, H 8.39; found: C 74.95, H 8.29.

Diphenylmethyl methyl sulfide (**11c**) [20]. *GP 3*. FCC (petether/CH_2Cl_2 3:1). Yield: 224 mg (52%). Colorless solid. M.p. 29–31° ([20]: 30–31°C). IR (KBr): 3095–2825, 1490, 1450, 1420, 1080. ^{1}H-NMR (600 MHz): 7.46–7.42, 7.36–7.31, 7.27–7.22 (3*m*, 10 arom. H, 4:4:2); 5.08 (*s*, 1 H); 2.01 (*s*, MeS). ^{13}C-NMR (151 MHz): 141.3 (*s*, 2 arom. C); 128.5, 128.3, 127.1 (3*d*, 10 arom. CH); 56.1 (*d*, CH)); 15.8 (*q*, MeS). ESI-MS: 215 (4, $[M+1]^+$), 167 (100, $[M–MeS]^+$).

*10,11-Dihydro-5*H-*dibenzo[*a,d*]cyclohepten-5-yl methyl sulfide* (*Dibenzosuber-5-yl methyl sulfide*) (**11d**). *GP 3*. FCC (petether/CH_2Cl_2 3:1). Yield: 197 mg (41%). Colorless solid. M.p. 72–73°. IR (KBr): 3060–2830, 1490, 1445, 1425. ^{1}H-NMR (600 MHz): 7.25–7.12 (*m*, 8 arom. H); 4.93 (*s*, 1 H); 3.85–3.78, 2.96–2.89 (2*m*, 2 H each, -CH_2CH_2-); 1.99 (*s*, MeS). ^{13}C-NMR (151 MHz): 140.7, 137.4 (2*s*, 2 arom. C); 130.9, 130.6, 127.7, 125.8 (4*d*, 8 arom. CH); 58.5 (*d*, CH)); 33.0 (*t*, -CH_2CH_2-); 16.8 (*q*, MeS). ESI-MS: 193 (100, $[M–MeS]^+$). Anal. calc. for $C_{16}H_{16}S$ (240.37): C 79.95, H 6.71; found: C 80.03, H 6.66.

Methyl phenyl(thien-2-yl)methyl sulfide (**11e**). *GP 3*. FCC (petether/CH_2Cl_2 4:1). Yield: 39 mg (9%). Pale orange oil. IR (film): 3100–2825, 1600, 1495, 1450, 1435, 1230. ^{1}H-NMR (600 MHz): 7.46 (br. *d*, *J* H7.7, 2 H(Ph)); 7.36–7.32 (*m*, 2 H(Ph)); 7.29–7.25 (*m*, 1 H(Ph)); 7.22 (br. *dd*, *J* H5.0, 0.9, 1 H(Th)); 6.96–6.91 (*m*, 2 H(Th)); 5.25 (*s*, 1 H); 2.05 (*s*,

MeS). ^{13}C-NMR (151 MHz): 145.9, 141.1 (2*s*, 2 arom. C); 128.6, 128.1, 127.6 (3*d*, 5 CH(Ph)); 126.6, 125.7, 125.1 (3*d*, 3 CH(Th)); 51.2 (*d*, CH); 16.0 (*q*, MeS). ESI-MS: 221 (27, $[M+1]^+$), 173 (100, $[M-\text{MeS}]^+$). Anal. calc. for $C_{12}H_{12}S_2$ (220.36): C 65.41, H 5.49; found: C 65.41, H 5.63.

Di(ferrocenyl)methyl methyl sulfide (**11f**). According to *GP 3*, di(ferrocenyl)thioketone (77 mg, 0.186 mmol) was reacted with LDA (0.30 ml, 0.60 mmol) and MeI (171 mg, 0.75 μl, 1.2 mmol). FCC (petether/CH_2Cl_2 3:1). Yield: 30 mg (37%). Orange solid. M.p. 107–108°. IR (KBr): 3120–2855, 1635, 1410, 1105, 1000. ^{1}H-NMR (600 MHz): 4.46 (*s*, 1 H); 4.26, 4.16, 4.13 (3 br. *s*, 18 H, 2:4:12); 1.88 (*s*, MeS). ^{13}C-NMR (151 MHz): 91.4 (*s*, 2 arom. C); 69.0 (*d*, 10 arom. CH); 68.0, 67.8, 67.09, 67.07 (4 *d*, 8 arom. CH); 45.3 (*d*, CH); 15.8 (*q*, MeS). ESI-MS: 430 (26, M^+), 383 (100, $[M-\text{MeS}]^+$). EI-HRMS: calc. for $C_{22}H_{22}Fe_2S$ $[M]^+$: 430.0141; found: 430.0150.

REFERENCES

[1] G. Mlostoń, H. Heimgartner, in 'Targets in Heterocyclic Systems - Chemistry and Properties', Eds. O. A. Attanasi, D. Spinelli, Italian Society of Chemistry, Rome, 2006, Vol. 10, pp. 266–300.

[2] G. Mlostoń, H. Heimgartner, *Polish J. Chem.* **2000**, *74*, 1503; G. Mlostoń, H. Heimgartner, in 'The Chemistry of Heterocyclic Compounds, Vol. 59: Synthetic Applications of 1,3-Dipolar Cycloaddition Chemistry Toward Heterocycles and Natural Products', Eds. A. Padwa, W. H. Pearson, J. Wiley & Sons, New York, 2002, pp. 315–360.

[3] H. Heimgartner, *Phosphorus, Sulfur and Silicon* **1991**, *58*, 281.

[4] G. Mlostoń, A. Linden, H. Heimgartner, *Helv. Chim. Acta* **1991**, *74*, 1386.

[5] G. Mlostoń, M. Petit, A. Linden, H. Heimgartner, *Helv. Chim. Acta* **1994**, *77*, 435; M. Petit, A. Linden, G. Mlostoń, H. Heimgartner, *Helv. Chim. Acta* **1994**, *77*, 1076.

[6] a) G. Mlostoń, A. Linden, H. Heimgartner, *Pol. J. Chem.* **1997**, *71*, 32; b) G. Mlostoń, A. Linden, H. Heimgartner, *Helv. Chim. Acta* **1998**, *81*, 558; c) A. Gebert, A. Linden, G. Mloston, H. Heimgartner, *Heterocycles* **2002**, *56*, 393; d) G. Mlostoń, K. Urbaniak, H. Heimgartner, *Helv. Chim. Acta* **2002**, *85*, 2056; e) A. Gebert, H. Heimgartner, *Helv. Chim. Acta* **2002**, *85*, 2073; f) A. Gebert, A. Linden, G. Mlostoń, H. Heimgartner, *Pol. J. Chem.* **2003**, *77*, 157; g) A. Gebert, A. Linden, G. Mlostoń, H. Heimgartner, *Pol. J. Chem.* **2003**, *77*, 867.

[7] J. W. Lown, in '1,3-Dipolar Cycloaddition Chemistry', Ed. A. Padwa, J. Wiley & Sons, New York, 1984, Vol. 1, pp. 653–732; L. M. Harwood, R. J. Vickers, in 'The Chemistry of Heterocyclic Compounds, Vol. 59: Synthetic Applications of 1,3-Dipolar Cycloaddition Chemistry Toward Heterocycles and Natural Products', Eds. A. Padwa, W. H. Pearson, J. Wiley & Sons, New York, 2002, pp. 169–252; C. Najera, J. M. Sansano, *Curr. Org. Chem.* **2003**, *7*, 1105.

[8] R. Beugelmans, G. Negron, G. Roussi, *J. Chem. Soc., Chem. Commun*. **1983**, 31; R. Beugelmans, J. Chastanet, G. Roussi, *Heterocycles* **1987**, *26*, 3197; J. Chastanet, G. Roussi, *J. Org. Chem.* **1988**, *53*, 3808.

[9] W. I. I. Bakker, P. L. Wong, V. Snieckus (Original Commentary), and J. M. Warrington, L. Barriaul (Update), in 'Encyclopedia of Reagents for Organic Synthesis', 2nd Edition, Eds. L. A. Paquette, D. Crich, P. L. Fuchs, G. A. Molander, J. Wiley & Sons, Chichester, 2009, Vol. 8, p. 6165.

[10] a) A. Wang, E. Biehl, *Arkivoc* **2002** (i), 71; b) E. C. Ashby, A. K. Deshponde, G. S. Patil, *J. Org. Chem.* **1995**, *60*, 663; c) N. De Kimpe, Z. P. Yao, N. Schamp, *Tetrahedron Lett.* **1986**, *27*, 1707; d) G. R. Newkome, D. C. Hager, *J. Org. Chem.* **1982**, *47*, 599; e) C. Shen, C. Ainsworth, *Tetrahedron Lett.* **1979**, *20*, 89.

[11] G. Wittig, C. N. Rentzea, M. Rentzea, *Liebigs Ann. Chem.* **1971**, *744*, 8.

[12] C. Jenny, P. Wipf, H. Heimgartner, *Helv. Chim. Acta* **1986**, *69*, 1837; J. Shi, H. Heimgartner, *Helv. Chim. Acta* **1996**, *79*, 371.

[13] C. Jenny, H. Heimgartner, *Helv. Chim. Acta* **1986**, *69*, 773; J. Shi, A. Linden, H. Heimgartner, **2013**, *96*, 1462.

[14] H. Heimgartner, G. MlostoD, J. RomaDski, in 'Electronic Encyclopedia of Reagents for Organic Synthesis', Eds. L. Paquette, J. Rigby, D. Crich, P. Wipf, John Wiley & Sons, Chichester, West Sussex, PO19 8SQ, UK, Article RN00504.

[15] a) J. RomaDski, G. MlostoD, *Synthesis* **2002**, 1355; b) C. E. Read, F. J. C. Martins, A. M. Viljoen, *Tetrahedron Lett.* **2004**, *45*, 7655.

[16] S. R. Wilson, G. M. Georgiadis, H. N. Khatri, J. E. Bartmess, *J. Am. Chem. Soc.* **1980**, *102*, 3577.

[17] A. Linden, J. RomaDski, G. MlostoD, H. Heimgartner, *Acta Crystallogr., Sect. C* **2005**, *61*, o221; J. RomaDski, G. MlostoD, *Arkivoc* **2007** (vi) 179; J. RomaDski, G. MlostoD, H. Heimgartner, *Helv. Chim. Acta* **2007**, *90*, 1279.

[18] R. S. Varma, D. Kumar, *Org. Lett.* **1999**, *1*, 697.

[19] M. I. Hegab, A. B. A. El-Gazzar, I. S. Farag, F. A. Gad, *Sulfur Lett.* **2002**, *25*, 79.

[20] W. Muramatsu, K. Nakano, C.-J. Li, *Org. Lett.* **2013**, *15*, 3650.

[21] J. L. Mieloszynski, C. G. Andrieu, M. Schneider, D. Paquer, *Recl. Trav. Chim. Pays-Bas* **1985**, *104*, 9.

[22] G. MlostoD, K. Urbaniak, K. G•bicki, P. Grzelak, H. Heimgartner, *Heteroatom Chem.* **2014**, *25*, submitted.

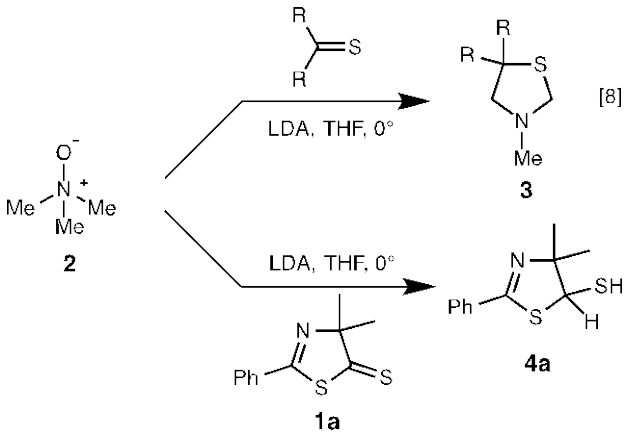
[23] E. Campaigne, W. B. Reid, *J. Am. Chem. Soc.* **1946**, *68*, 769.

[24] A. Schönberg, K.-H. Brosowski, E. Singer, *Chem. Ber.* **1962**, *95*, 2144; G. MlostoD, G. K. S. Prakash, G. A. Olah, H. Heimgartner, *Helv. Chim. Acta* **2002**, *85*, 1644.

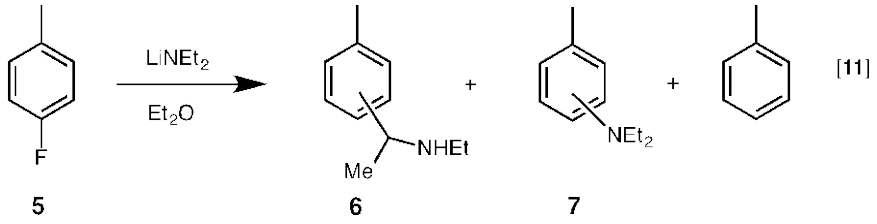
[25] K. Maruyama, T. Katagiri, *J. Phys. Org. Chem.* **1989**, *2*, 205.

[26] E. J. Campbell, H. Zhou, S.-B. T. Nguyen, *Angew. Chem.* **2002**, *114*, 1062; *Angew. Chem. Int. Ed.* **2002**, *41*, 1020.

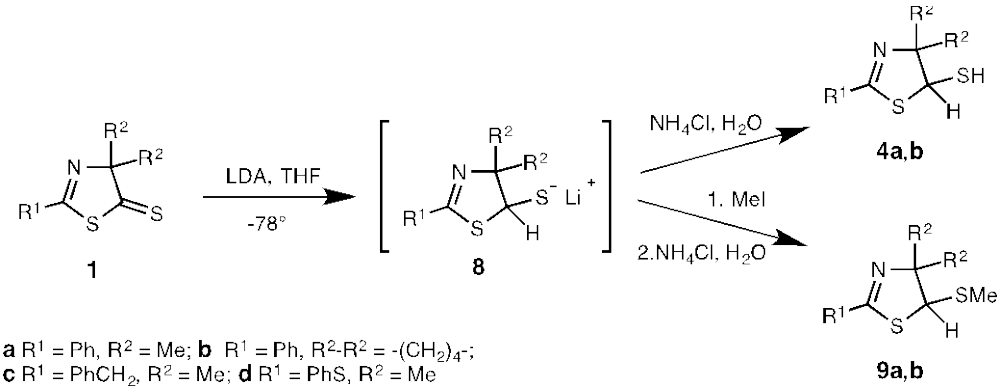
Scheme 1



Scheme 2

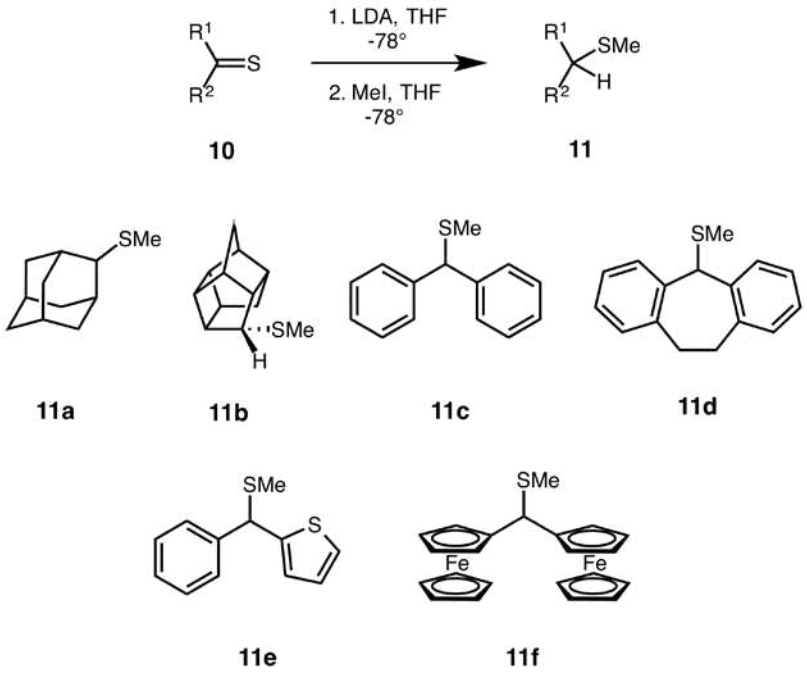


Scheme 3

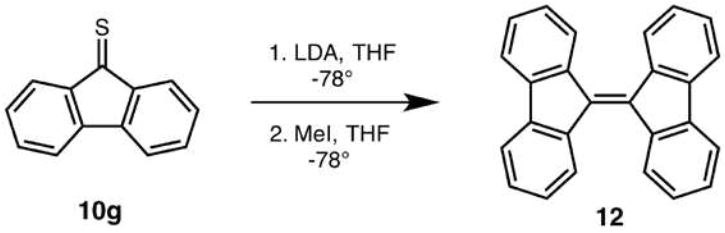


a R^1 = Ph, R^2 = Me; **b** R^1 = Ph, R^2-R^2 = -$(CH_2)_4$-;
c R^1 = $PhCH_2$, R^2 = Me; **d** R^1 = PhS, R^2 = Me

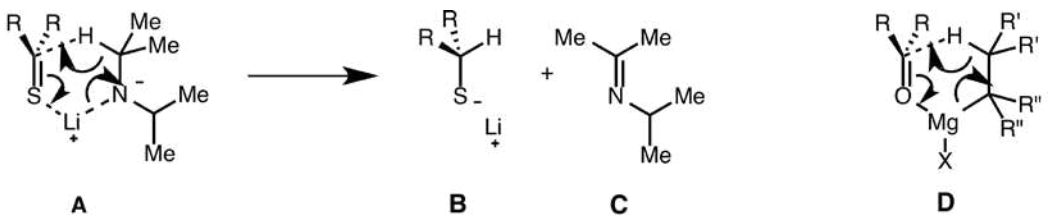
Scheme 4



Scheme 5



Scheme 6



Graphical Abstract